Silicon Valley—A Chip off the Old Detroit Bloc

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I. Introduction

Silicon Valley is the envy of the world, one of the most celebrated regions of economic growth in modern history. We are accustomed to thinking of it as the outgrowth of a unique confluence of ingredients. One is its roots as an early incubator of now famous electronics firms, including Hewlett Packard, Varian Associates, and Litton Industries. Another is Stanford University, led by its innovative dean of engineering and later Provost, Frederick Terman. Yet another is its culture of vertically specialized, non-hierarchically organized firms that define a virtual network of producers. Couple all these ingredients with the growth of the semiconductor industry and the emergence of venture capitalists in Silicon Valley to support it and you get a seemingly unprecedented wave of new, spinoff enterprises in Silicon Valley formed by top employees of incumbent semiconductor firms. Today, these Silicon Valley semiconductor spinoffs are legion, including such famous firms as Fairchild Semiconductor, National Semiconductor, Advanced Micro Devices (AMD), and Intel. Indeed, according to a well-known genealogy prepared by Semiconductor Equipment and Materials International (SEMI), over 100 semiconductor spinoffs arose in Silicon Valley through 1986. Nearly all of them were descended in one way or another from Fairchild, whose direct descendants are so numerous they have been dubbed the Fairchildren.

Many have heralded these semiconductor spinoffs as representing a new form of industry and regional development. Charles Sporck, the head of manufacturing at Fairchild during its formative era and later founder and leader of National Semiconductor, titled his recent book *Spinoff* to convey the importance of this new phenomenon. In his article on "The Splintering of the Solid-State Electronics Industry," Nilo Lindgren [1971], a senior fellow at *Innovation* Magazine, was so taken by the spinoff phenomenon in semiconductors that he speculated whether it defined a whole new type of high-technology enterprise never before seen. In a recent co-authored article entitled, "Learning the Silicon Valley Way," Gordon Moore, one of the traitorous eight that founded Fairchild and later went on to co-found Intel, similarly opined that "the central element in the history of Silicon Valley is the founding of a previously unknown type of regional, dynamic, high-technology economy" (Moore and Davis [2004, p. 7]) fueled by semiconductor spinoffs.

While there is widespread agreement about the importance of semiconductor spinoffs in the emergence of Silicon Valley, there is less agreement on the circumstances that gave rise to the spinoff phenomenon. In her well-know comparison of the evolution of Silicon Valley and Rt. 128, AnnaLee Saxenian [1994] sees all the ingredients listed above as important contributors to the spinoff-led growth of Silicon Valley. Her views are echoed by Christopher Lécuyer [2006] in his recent book on the roots of Silicon Valley. On the other hand, Moore and Davis [2004] downgrade the importance of factors such as Stanford and Hewlett Packard and say little about the importance of a Silicon Valley culture shaped by vertically specialized, less hierarchically organized firms that Saxenian celebrates. Everyone seems to agree, though, that Silicon Valley represents a new entrepreneurial phenomenon driven by spinoffs.

It will be argued that Silicon Valley is *not* at all a new phenomenon, and recognizing this provides insights into how agglomerations like Silicon Valley emerge. Silicon Valley appears to be *sui generis* because we know little about how the geographic structure of new industries evolves. Recent work on the historical automobile industry by Klepper [2006b] suggests, however, that the evolution of the auto industry around Detroit bears an uncanny resemblance to the evolution of the semiconductor industry around Silicon Valley. This is noteworthy because the automobile industry defined the Fordist method of production that is depicted as the antithesis of the "Silicon Valley way." Detroit also lacked an analog to Stanford, and while it had its share of machine shops and carriage producers, it was hardly the place the automobile industry might have been expected to flourish. Moreover, Klepper [2006b] contends that the success of the Detroit firms was confined to the spinoffs that entered there, suggesting that it was the spinoff phenomenon and not agglomeration economies that drove the agglomeration of the automobile industry around Detroit. In the parlance of Moore and Davis [2004], the lesson from Detroit is that the conditions necessary for the emergence of Silicon Valley may have been remarkably simple, albeit rare.

The argument is developed as follows. In Section II, the evolution of the semiconductor industry is reviewed. Using early market share data compiled by Tilton [1971] coupled with annual data on the sales of larger merchant North American semiconductor producers from 1974 to 2002 compiled by Integrated Circuit Engineering

(ICE), a private consulting firm, the role of spinoffs in the agglomeration of the semiconductor industry in Silicon Valley is traced. In Section III, the spinoff process in the semiconductor industry is dissected. Various sources, including the Silicon Valley genealogy prepared by SEMI, are used to identify the spinoffs of the producers on the ICE list. Analyses are conducted of the rate at which firms spawned spinoffs and the performance of the spinoffs. The impetus for the leading spinoffs is also discussed. In Sections IV and V, comparable analyses of the evolution of the automobile industry and its spinoffs are conducted. In Section VI, parallels between the semiconductor and automobile industries are discussed and implications are drawn for how agglomerations emerge and the role that public policy can play in furthering the process.

II. Evolution of the Semiconductor Industry and its Agglomeration in Silicon Valley

Semiconductor diodes and rectifiers were sold before World War II, but the transistor effectively started the semiconductor industry. It was invented in 1948 by three Bell Lab scientists, including William Shockley, who later founded the first semiconductor firm in Silicon Valley, Shockley Laboratories. Under antitrust pressure, AT&T, Bell's parent, agreed to produce transistors only for its own needs—i.e., to be a captive producer. It liberally licensed its patents and held symposia to diffuse transistor technology to other firms, which led many firms to enter the merchant (i.e., non-captive) market. Tilton [1971, p. 66] presents data on the market share of the leading merchant semiconductor producers in the early years of 1957, 1960, 1963, and 1966. This is supplemented in Table 1 with market share data from the ICE listing for 1975, 1980, 1985, and 1990 for firms that were among the top ten producers in any of these years and also for the leaders in the earlier years.

The transistor substituted for the vacuum tube in many applications. Consequently, many of the early leaders, including General Electric, RCA, Raytheon, and Sylvania, were producers of vacuum tubes and other electronics products. Most of the other leaders were also established electronics producers, including Motorola, TRW, Hughes, General Instrument, and Delco Radio. Texas Instruments (TI) was also an electronics producer, but younger and smaller than the others. Among the early leaders, only Transitron and Fairchild were new firms. Transitron was founded by two brothers, one of whom had worked at Bell Labs. Fairchild, which was the second firm in Silicon Valley, was formed by the traitorous eight employees of Shockley Laboratories.

Before the entry of Fairchild, semiconductor production was concentrated in three centers: Boston, New York, and Los Angeles. Tilton [1971, pp. 52-53] presents a list of transistor producers and the years they produced in the period 1951-1968, and a similar list was compiled for 1952-1980 from annual listings of transistor producers in *Thomas' Register of American Manufacturers*. Among the leaders of the industry in 1957, *Thomas' Register* listed Raytheon and Transitron in the Boston area, Sylvania and General Instrument in the New York area, and Hughes and TRW in Los Angeles. Each area also had a contingent of lesser but significant firms listed, including Hytron/CBS, Clevite, Sprague, Unitrode, and Crystalonics in the Boston area, Tung Sol, Industro Transistor, and Silicon Transistor in the New York area, and Nucleonic and Hoffman in Los Angeles. The other significant producer as of 1957 was Texas Instruments (TI), which was located in Dallas, TX. Early semiconductors were produced from germanium, but germanium had many limitations and was eventually replaced by silicon in nearly all semiconductor devices. TI was the first producer of silicon transistors in 1954, which gave it a two to three year lead over its competitors that enabled it to become the industry leader with 20% of the market as of 1957 (Tilton [1971, p. 65]).

Prior to the entry of Fairchild, production of semiconductors in Silicon Valley was negligible. William Shockely located his firm in Silicon Valley, where he was reared, but he was a dysfunctional manager and Shockley Laboratories was not successful. Shockley was a brilliant scientist and an excellent judge of talent, however, and Fairchild was successful immediately. Along with TI, Fairchild pioneered the development of silicon transistors. It invented the planar manufacturing process, which eventually was adopted by all semiconductor producers. It also developed the integrated circuit (IC) along with TI, and was the first to produce ICs using the planar process. By 1960 Fairchild had captured 5% of the market, which grew to 13% as of 1966 with the growth in sales of ICs.[1] The other major successful firm in this era was Motorola, which

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[1] In the same year, Fairchild was estimated to account for 30% of the IC market (Lécuyer [2006, p. 249]).

based its semiconductor production in Phoenix, AZ. Initially it produced semiconductors for its own use but then entered the merchant market around 1958 by capitalizing on developments at TI and Fairchild. It captured 5% of the market by 1960, which increased to 12% as of 1966.

Fairchild was the first spinoff in Silicon Valley and the font of many subsequent spinoffs. The Silicon Valley genealogy compiled by SEMI was used to identify the semiconductor spinoffs in Silicon Valley, which are defined as semiconductor producers founded by employees of other semiconductor firms.[2] All of the founders of each spinoff are listed in the geneaology. The parent of each spinoff was defined as the prior employer of the first listed founder.

According to the Silicon Valley genealogy, the first spinoff in Silicon Valley after Fairchild was Rheem, which was formed in 1959 by employees of Hughes and Fairchild. Two years later it was acquired by Raytheon. The next two spinoffs in Silicon Valley were Signetics and Amelco, both of which were spinoffs of Fairchild. Seven more spinoffs entered in Silicon Valley between 1962 and 1966, including two from Fairchild. The spinoff rate then increased sharply. Three were founded in 1967, eleven in 1968, and nine in 1969. Eight of these 23 spinoffs came out of Fairchild, including National Semiconductor, Intel, and AMD, all of which became leading producers. Over the next six years through 1975 an additional 26 semiconductor producers, nearly all spinoffs, entered in Silicon Valley, including four more from Fairchild.

Table 1 reflects the dramatic effect of the spinoffs on the agglomeration of the semiconductor industry in Silicon Valley through 1975. Fairchild was the only leading semiconductor producer based in Silicon Valley in 1966, and it accounted for 13% of the

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[2] Most of the spinoffs were new firms, but a few were organized as new subsidiaries of nonsemiconductor firms or involved a reconstitution of existing semiconductor firms in which the new "founders" were given an ownership interest. Fairchild, for example, was financed by and became a subsidiary of Fairchild Camera and Instrument, a Long Island military contractor. National Semiconductor was an example of a reconstituted firm. It was founded in Connecticut in 1959 but by 1967 was floundering, and it brought in Charles Sporck, the head of manufacturing at Fairchild, to reconstitute its efforts in Silicon Valley, effectively giving birth to a new firm. Following general practice, National was classified as a spinoff of Fairchild. MOS Technology represents a similar occurrence. It was originally founded by an employee of General Instrument and two others to produce calculator chips in Norristown, PA. It was transformed into a producer of microprocessors after eight employees from Motorola joined it to develop a low cost alternative to Motorola's initial microprocessor. Accordingly, MOS Technology was classified as a spinoff of Motorola.

market. By 1975 the share of the market accounted for by the leading Silicon Valley semiconductor firms had increased to 38% and the joint market share of all the Silicon Valley producers on the ICE list was 43%. Of the eight firms that ascended to the ranks of the leaders in 1975, six were spinoffs of merchant producers. Five of them were located in Silicon Valley, including Signetics, National, Intel, and AMD, all Fairchild spinoffs, and, AMI, which was a second generation spinoff of Fairchild. The other leading spinoff, Mostek, came out of TI and located near it in the Dallas area.[3] The success of the spinoffs largely came at the expense of the tube producers and diversified electronics firms, a number of which retreated into captive production.[4] The main exceptions were TI and Motorola, which remained leading producers.

After 1975 the entry of spinoffs in Silicon Valley declined for a few years and then picked up again in the 1980s. Between 1980 and 1986, which is the last year of the Silicon Valley genealogy, 49 firms entered, nearly all spinoffs. Table 1 indicates that this did not lead to a major change in the joint market share of the Silicon Valley firms, which increased by just a few percentage points and then topped out in 1985 at 49%. Three firms, all spinoffs, one from Fairchild (LSI Logic), another descended from Fairchild (VLSI Technology), and a third from Mostek (Micron Technology), made it into the ranks of the leaders in the 1980s. However, none of these firms captured a market share of over 3%. Intel and secondarily AMD increased their market shares, while Fairchild, weakened by the numerous employees that had defected to found their own firms, declined and was eventually acquired by National in 1987. The other leaders, including TI, Motorola, and National, maintained their market shares.

In total, over 100 firms entered the semiconductor industry in Silicon Valley between 1957 and 1986, nearly all of which were spinoffs. Together the Silicon Valley

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[3] The other two new leaders in 1975 were Analog Devices, which was located in the Boston area, and Harris, which produced semiconductors in Melbourne, FL. The founder of Analog had previously started another firm in the Boston area, and before that had worked for Hewlett Packard in Silicon Valley. Harris was a diversified electronics firm.

[4] The other firm that declined sharply was Transitron. Apparently it did little R&D (Braun and MacDonald [1979, p. 71]), which soon caused it to fall behind the other leaders of the industry and eventually exit in 1986.

spinoffs captured nearly 50% of the market,[5] and the population of Silicon Valley (Santa Clara County) grew tremendously, increasing from 642,315 in 1960 to 1,295,071 in 1980 (Scott and Angel [1987, p. 891]). Outside of Silicon Valley, spinoffs were less prominent. Among the 101 merchant producers on the ICE listings that entered by 1986, the backgrounds of 92 of them could be traced.[6] Fifty-six of the 92 were located in Silicon Valley, and 53 of these were spinoffs. In contrast, only 15 of the 36 located outside of Silicon Valley were spinoffs, and many of the leaders outside of Silicon Valley, such as TI, Motorola, RCA, Harris, and General Instrument, were not spinoffs. Thus, consistent with all observers, spinoffs were particularly a Silicon Valley phenomenon, and they were key to the agglomeration of the semiconductor industry there.

III. Spinoff Analysis

Greater insight can be developed concerning the spinoff process by analyzing which firms spawned spinoffs, the location of parents and their spinoffs, the relationship between the performance of spinoffs and their parents, and the primary reasons the leading spinoffs were formed.

A. Fertility and Location

Brittain and Freeman [1986] conducted one of the earliest studies of spinoffs, using an early version of the Silicon Valley genealogy to analyze the factors influencing the rate at which Silicon Valley semiconductor producers spawned spinoffs. Updating and expanding to encompass non-Silicon Valley firms, the data from the ICE listings were used to analyze the rate at which all 101 merchant producers on the ICE listings spawned spinoffs through 1986, the last year of the Silicon Valley genealogy. Based on

[5] The share of semiconductor production that actually took place in Silicon Valley was considerably smaller than 50%. The leading Silicon Valley firms established production sites outside of Silicon Valley and assembled components in other parts of the world to save on labor costs. Most of the captive producers were also located outside of Silicon Valley, and they produced a large volume of semiconductors, led by IBM, which produced more semiconductors than any of the merchant producers in the 1970s and 1980s.

[6] Nearly all the Silicon Valley firms could be traced from the Silicon Valley genealogy. Numerous sources were used to track the other firms, including the web site www.antiquetech.com, which was particularly helpful. Spinoffs and their founders were defined using the same criteria that were applied to the Silicon Valley firms.

the 92 ICE producers whose heritages could be traced, the spinoffs of each of the 101 merchant producers were identified. For the Silicon Valley firms, the Silicon Valley genealogy was also used to identify their spinoffs that did not make it onto the ICE listings (because they were too small or entered before 1974). Thus, the list of spinoffs for the Silicon Valley firms is comprehensive,[7] whereas the list for the non-Silicon Valley firms is limited to their later and more prominent spinoffs. In total, 91 spinoffs were identified.

Table 2 lists the 27 firms that accounted for the 91 spinoffs. They are organized by whether they were located in Silicon Valley and are ordered according to their number of spinoffs and date of entry. For each firm, its total number of spinoffs, the number on the ICE list, and the number that made it into the top 20 ICE producers in one or more years are recorded, as is whether the firm itself made it into the top 20 ICE producers in one or more years.

Clearly, Fairchild stands out with 24 spinoffs. Its spinoff National also stands out with nine spinoffs. The next two most prolific parents, Intel and Signetics with 6 and 5 spinoffs respectively, are also spinoffs of Fairchild. Intersil, with four spinoffs, was not a spinoff of Fairchild, but was founded by one of the founders of Fairchild (who had previously founded two other spinoffs). Thus, it is immediately evident how influential Fairchild was in the formation of spinoffs. More generally, the top semiconductor firms dominated the spinoff process. Seventeen of the 27 parents were top 20 producers and collectively spawned 73 of the 91 spinoffs.

To convey the annual rate at which firms spawned spinoffs, a firm's total number of spinoffs is divided by the total number of years it produced semiconductors through 1986. Entry and exit years could be determined for 99 of the 101 producers on the ICE list, and among these 99 firms, 43 made it into the top 20 producers in one or more years. These 43 firms collectively produced for 695 years and the other 56 firms collectively produced for 510 years. Therefore, the annual rate at which firms spawned spinoffs was 73/695 = .105 for top 20 firms and 18/510 = .035 for other firms. These fractions are

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[7] The only spinoffs of the Silicon Valley firms that would not have been identified are those that located outside of Silicon Valley and did not make onto the ICE listings. Judging, however, from the tendency of

significantly different at the .01 level, as will be true for most of the comparisons reported below, and subsequently only comparisons not significantly different at the .05 level will be noted. Restricting this comparison to firms located in Silicon Valley (for which the listing of spinoffs is comprehensive), the analogous rates are 61/374 = .163 and 18/245 = .073. Thus, for each year they produced, the top 20 firms were two to three times as likely as the other firms to spawn spinoffs. Clearly, much of this differential is due to Fairchild and its 24 spinoffs. But looking outside of Silicon Valley, the annual spinoff rate was also markedly higher for the leading firms—12/321 = .038 for top 20 firms versus 0/265 = 0 for the non-top 20 firms.

Multiple factors could explain the greater fertility of the leading producers. One is their greater size, which means they had more employees who could potentially found spinoffs. Indeed, on average the top 20 firms were well over 10 times larger than the other firms, hence they actually had a lower annual spinoff rate relative to their size than other firms. The significance of this, though, is unclear. Founders of spinoffs tended to be high level employees, including a number of individuals that founded multiple spinoffs. If employees need high-level experience to profitably start their own firm, it is not clear whether larger firms really have more potential spinoff founders, and surely do not have proportionately more potential spinoff founders, than other firms. An alternative explanation for the greater fertility rate of top firms is that they have superior employees who are more likely to be able to found profitable spinoffs. Another possibility is that better firms provide superior environments for their employees to gain the organizational knowledge needed to form a profitable spinoff. These possibilities will be considered further in the analysis of the performance of the spinoffs.

Table 2 indicates that Silicon Valley firms dominated the spawning process, accounting for 79 of the 91 spinoffs. Standardizing by the number of years of production, the annual fertility rate of Silicon Valley firms was 79/619 = .128 versus 12/586 = .020 for firms outside of Silicon Valley. In part, this difference is due to the more comprehensive identification of spinoffs for the Silicon Valley firms. But considering only the spinoffs that made it onto the ICE listings, the annual fertility rate

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spinoffs of Silicon Valley firms to locate in Silicon Valley, as discussed below, few spinoffs of Silicon was 42/619 = .068 for the Silicon Valley firms versus 10/586 = .017 for the firms elsewhere. Excluding Fairchild as an outlier, the Silicon Valley rate is still 28/589 = .048 versus .017 for the firms elsewhere. Thus, it appears that Silicon Valley firms were more likely to spawn spinoffs. Restricting further the comparison to top 20 producers to control for firm quality, the fertility rate of the top 20 Silicon Valley producers is 35/374 = .094 versus 10/321 = .031 for the top 20 producers elsewhere. Again excluding Fairchild, the fertility rate of the top 20 Silicon Valley producers of 21/344 = .061 is still nearly twice that of the top 20 producers elsewhere (but not significantly different from it). Moreover, among the non-top 20 firms, the fertility rate is 8/245 = .033 for Silicon Valley firms versus 0/265 = 0 for firms elsewhere. Thus, even controlling for firm quality, Silicon Valley firms had a higher fertility rate.

Again, multiple factors may have been at work. One is the blossoming of the venture capital industry in Silicon Valley (cf. Kenney and Florida [2000]), which facilitated the formation of new firms there. Another is a kind of demonstration effect in which successful spinoffs induced others to form spinoffs. Another factor cited by Saxenian [1994] and others is the extent to which semiconductor firms in Silicon Valley were more vertically specialized than semiconductor firms elsewhere (cf. Scott and Angel [1987]), making it easier for entrants to find suppliers to complement their expertise.

Some insight can be gained about these factors from where spinoffs located vis a vis their parents. Most founders located their spinoffs close to home, perhaps for both economic and social reasons. This was especially true of the spinoffs of the Silicon Valley firms, nearly all of which located in Silicon Valley. Four of the 12 spinoffs of non-Silicon Valley firms also located there. Each had roots in Silicon Valley—three had non-primary founders there and the founder of the fourth previously worked for Fairchild. The fact they chose to locate in Silicon Valley is consistent with the greater availability of capital and support for startups there.

Most of the other spinoffs of the non-Silicon Valley firms also located close to their parents. Two prominent exceptions, both of which made it into the top 20 producers, were Micron Technology and MOS Technology. Micron, which was a spinoff

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Valley firms are likely to have been missed.

of Mostek (of Dallas, TX), was founded in a garage in Boise, ID, where it was subsequently able to raise capital. MOS Technology, classified as a spinoff of Motorola (of Phoenix, AZ),[8] located in Norristown, PA, where its "partner" fabricated its chips. On the one hand, these locations are consistent with the availability of capital and support, both abundant in Silicon Valley, being important determinants of the location of producers. On the other hand, they illustrate that it was not necessary to locate in Silicon Valley to gain access to capital or specialized suppliers. Indeed, both TI and Motorola prospered over time despite not being located in Silicon Valley, as did a host of other firms such as Analog Devices and Harris.

Further insight into the spinoff process can be gleaned by examining when firms spawned spinoffs over their lifetime. All of the spinoffs occurred during the semiconductor lifetimes of their parents. Table 3 reports the annual fertility rate of firms in consecutive five-year age brackets from ages 1-5 to ages 36-40. When all firms are considered, the fertility rate rises steadily into the 16-20 age bracket and then declines sharply. If the analysis is limited to the 27 firms with one or more spinoffs, as would be the case if fixed effects were used to control for firm differences, the pattern is similar but the fertility rate is much closer for the age brackets 11-15 and 16-20.[9] Similar patterns were found when the tabulations were restricted to firms that survived 15 years or longer. Thus, it appears that firms were more likely to spawn spinoffs at middle age, which occurred somewhere between ages 10 and 20.

One other factor that may have influenced the timing and possibly occurrence of spinoffs is managerial frictions caused by certain types of control changes within firms. Brittain and Freeman [1986] found that spinoffs were more likely among Silicon Valley semiconductor firms after they were acquired by nonsemiconductor firms or appointed a new CEO from outside the firm. Only nine of the 27 parents were acquired and generally toward the end of the period studied, providing little basis to evaluate the effects of acquisitions on the incidence of spinoffs. Comprehensive data on CEO changes were not available to conduct an analysis comparable to Brittain and Freeman's of the effect of

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[8] See footnote 2 for the origins of MOS Technology

[9] For the parents, the rise from 6-10 to 11-15 and the fall from 16-20 to 21-25 is significant, whereas for all firms only the rise from 6-10 to 11-15 is significant.

CEO changes on the incidence of spinoffs. But the discussion below concerning the impetus for the leading spinoffs will bring out the importance of control changes in the formation of a number of the prominent semiconductor spinoffs.

B. Performance of Spinoffs

The performance of the spinoffs can be analyzed according to the performance of their parents. Parents are divided into two groups according to whether they were top 20 producers or not. The performance of their spinoffs is measured according to the fraction that made it onto the ICE listings (this can be computed only for the Silicon Valley firms) and the fraction that were top 20 producers. These fractions are reported in Table 4.

Overall, the Silicon Valley firms had 43 spinoffs that made it onto the ICE listings out of a total of 79 spinoffs. The likelihood of a spinoff making it onto the ICE listings was modestly higher for the spinoffs of the leading firms--.574 of the spinoffs of top 20 producers in Silicon Valley made it onto the ICE listings versus .444 of the spinoffs of the other Silicon Valley producers (difference not significant). Focusing on the likelihood of spinoffs making it into the top 20 producers, the difference is much starker. Among all top 20 producers (in and outside of Silicon Valley), 19 of their 73 spinoffs, or .260, made it into the top 20 producers versus 2 of 18, or .111, of the spinoffs of non-top 20 producers (difference not significant). Standardizing by years produced, the annual rate at which firms spawned spinoffs making it into the top 20 producers was 19/695 = .027 for top 20 producers versus 2/510 = .004 for the other producers. Moreover, both of the spinoffs of non-top 20 producers that made it into the top 20 had founders who previously had worked at top 20 producers, which was acknowledged to have contributed to their success (McCreadie and Rice [1989, p. 32]). It would thus appear that having a founder who had worked at a top 20 producer was virtually a necessary condition for a spinoff to become a top 20 producer.

This suggests that better firms had a higher fertility rate not merely because of their greater size but also because their spinoffs were better able to compete in the industry. Multiple factors could account for the superior performance of their spinoffs. One is that better firms may have had superior employees, at least on average, which could help explain their superior performance. Indeed, some of their employees that founded leading spinoffs, such as Robert Noyce, Gordon Moore, Andrew Grove, Charles

Sporck, and Jerry Sanders of Fairchild, Wilfred Corrigan, who started at Transitron and rose up the ranks of Motorola and Fairchild, and L.J. Sevin of Texas Instruments, were celebrated figures in the industry. It may also have been the case that working at a top firm provided distinctive lessons about organizing and competing at the highest levels, as was acknowledged regarding the two spinoffs of the lesser firms that made it into the ranks of the leaders. Either way, it seems likely that the greater fertility rate of the top 20 producers was not merely due to their greater size but also to conditions that enhanced the profitability of their spinoffs.

C. Origin of the Leading Silicon Valley Spinoffs

Further insight into the agglomeration of the semiconductor industry in Silicon Valley can be gained by tracing the origin of the spinoffs of the Silicon Valley merchant producers that attained the top 20 producers. Table 5 summarizes information about the impetus and main source of finance for the top Silicon Valley spinoffs whose origins could be traced.

Firms continually had to make difficult choices about which technologies to develop. Initially it was unclear whether germanium or silicon would be the best material for semiconductors. When ICs were developed, they were initially inferior to circuits composed of discrete devices and potentially infringed upon the markets of semiconductor customers. Metal Oxide Semiconductor (MOS) devices were slower than early, bipolar circuits and were unstable and difficult to make. Eventually, though, manufacturing problems were overcome and MOS devices proved to be superior for many applications because they enabled many more transistors to be packed onto chips. Similarly, Complementary Metal Oxide Semiconductor (CMOS) devices were extremely slow, but their low power needs ultimately facilitated even denser chips. Application specific ICs (ASICs) initially were not economical but MOS technology eventually changed that. Linear, or analog, devices, which are used for amplification and other non-digital applications, have always posed distinct technical and market challenges.

Initial technical and market uncertainties over these technologies led to conflicts and spinoffs in many top firms. Fairchild, for example, was formed to pursue the development of silicon transistors after Shockley abandoned this goal in favor of a new device he invented that proved to be difficult to manufacture (Lécuyer [2006, pp. 131-

139]). Amelco and Signetics were formed to develop ICs after Fairchild did not pursue them aggressively due to their initial inferior performance and fear of infringing on the markets of their customers (Lécuyer [2006, pp. 213-218], Sporck [2001, p. 70]). Intel was formed in part due to Gordon Moore's frustration with Fairchild's inability to develop MOS products despite being the industry leader in MOS research, which stemmed from the separation of R&D and manufacturing at Fairchild (Bassett [2002, pp. 172-173]). Linear Technology was founded by the head of National's analog division because he felt National treated analog devices as a means of getting into a better business rather than an attractive business of its own (Wilson {2004]). Cypress was formed to exploit CMOS technology after its parent, AMD, and other established firms were not interested in CMOS (Gilder [1989, p. 143]).

Another major challenge firms faced was how to compensate innovators and structure their organizations to harness scientific and technical advances for commercial benefit (Moore and Davis [2004]). Early on it was unclear how important stock options would prove to be in rewarding innovators and top managers. It was also unclear whether R&D should be conducted separately from manufacturing, as was common practice in other industries. Conflicts arose over these and related managerial issues, especially when firms were overseen by non-semiconductor firms that had financed or acquired them. Similar tensions arose when new management was brought in from outside the firm.

Many of these conflicts led to spinoffs and ultimately the decline of their parents. Electronic Arrays, for example, was formed after its parent, General Microelectronics (GME), was acquired by Philco, which canceled stock options and moved the company from Silicon Valley to Philadelphia (Lécuyer [2006, p. 263]). Within two years, Philco exited the industry. Intersil was similarly formed when its parent, Union Carbide, refused to give its leader stock options (Lécuyer [2006, pp. 263-264]). Union Carbide ended up selling off its semiconductor operation four years later and exiting the industry. The failure of Fairchild to grant more than meager stock options to its leading managers also figured prominently in the formation of National (Sporck [2001, pp. 207-214], Lécuyer [2006, pp. 259-261]). Other leading spinoffs were formed after changes in top management led to frictions and ultimately poor performance in incumbent firms. AMD was founded after Lester Hogan was brought in from Motorola to head Fairchild's parent and brought in new managers to run Fairchild (Sporck [2001, pp. 152-157]). Fairchild continued to flounder and was acquired by Schlumberger, a French firm. Schlumberger brought in its own management, which knew little about semiconductors, which led to the departure of Fairchild's CEO, Lester Corrigan, and ultimately the decline and sale of Fairchild to National (Walker [1992, pp. 54-57]). Corrigan went on to found LSI Logic to produce ASICs, a market Fairchild had pursued earlier but then abandoned. Similarly, VLSI was formed to produce ASICs after Synertek was acquired by Honeywell, a computer manufacturer who also brought in its own management to run the company (Walker [1992, pp. 184-186, 195-197]). Seven years later Honeywell sold Synertek and exited the industry.

The spinoffs were financed predominantly by downstream firms and venture capitalists, many of whom were past employees of successful semiconductor firms. Both had their own, distinctive sources of knowledge that they could draw upon to evaluate prospective spinoffs. The leading spinoffs they financed expanded the scope of semiconductor products developed in Silicon Valley and prodded the existing firms to expand their activities. They also compensated for flaws in the way some companies like Fairchild were designed and provided a safe haven for talented individuals caught in firms dragged down by managers from other cultures. It is especially these roles that have led numerous observers to trumpet the importance of spinoffs in the growth of the semiconductor industry in Silicon Valley (Saxenian [1994, p. 112], Sporck [2001, pp. 268-271], Moore and Davis [2004]).

IV. Evolution of the Automobile Industry and its Agglomeration in Detroit

The U.S. automobile industry is generally dated as beginning in 1895. Various sources are available to trace entrants into the industry and their backgrounds. Based on Smith [1968], a total of 725 entrants were identified from 1895 to 1966. Smith and the *Standard Catalog of American Cars* (Kimes [1996]) were used to determine the year of entry, year of exit, base location, and heritage of each entrant.[10] Firms with one or more founders that were employees of incumbent automobile firms were classified as spinoffs, which yielded a total of 145 spinoffs. Bailey [1971] and FTC [1939] were used to compute annual market shares of the leading firms, which are reported every five years from 1900 to 1925 in Table 6.

Figure 1 plots the annual number of entrants, exits, and producers from 1895 to 1966. Entry into the industry was concentrated in its first 15 years. From 1895 to 1900 69 firms entered, followed by 184 firms in 1901-1905, with entry peaking at 82 in 1907. Entry remained high for the next three years and then dropped to approximately 15 firms per year from 1911-1922, after which only 15 firms entered through 1966. The number of firms peaked at 272 in 1909. Subsequently it fell sharply, dropping to 9 in 1941 despite enormous growth in the industry's output. The industry evolved to be a tight oligopoly dominated by three famous Detroit-based firms, General Motors, Ford, and Chrysler.

Initially the industry had little presence in Detroit. The first 69 entrants from 1895-1900 were concentrated in New England, New York, and the Midwest, with no firm entering in the Detroit area, which was defined as the 100 radius in Michigan around Detroit.[11] The initial entrants were a mixture of diversifiers and new firms with backgrounds in related industries, especially bicycles, carriages and wagons, and engines. The four leaders in 1900 listed in Table 6 are illustrative. Pope, which was located in Hartford, CT, was the leading U.S. producer of bicycles when it diversified into automobiles in 1895. Locomobile, which was located in Bridgeport, CT, was a new firm founded by two successful businessmen. It entered by purchasing the business of the

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[10] The *Standard Catalog* provides a brief description of the founding of each automobile producer. It was used to identify spinoffs. A firm was classified as a spinoff if one or more of its organizers had previously worked at another automobile producer on Smith's list Its parent was classified as the last known automobile employer of the most influential founder (in most cases of multiple automobile founders, all of them previously worked for the same firm). See Klepper [2002] for a detailed description of the procedures followed to identify spinoffs and parents and also how acquisitions were handled in defining entrants and exiters.

[11] In addition to Detroit, the area includes the following locations in Michigan: Adrian, Chelsea, Flint, Jackson, Marysville, Oxford, Plymouth, Pontiac, Port Huron, Sibley, Wayne, and Ypsilanti. The boundaries of this region were chosen to reflect multiple locations of some of the firms and movements of others within the region.

Stanley Brothers, leading producers of steam powered automobiles located in Watertown, MA. Knox was a spinoff of another early producer, Overman, located in Springfield, MA, and White Sewing Machine was a leading producer of sewing machines in Cleveland, Ohio that diversified into automobiles. A number of the other significant early entrants were also located in New England and Cleveland, including Duryea, Stanley Brothers, and Waltham in New England and Winton, F. B. Stearns, Baker, and Peerless in Cleveland, making these two areas the early centers of the industry.

Initially, cars were powered by electricity, steam, or gasoline, but the internal combustion engine began to dominate the industry by the early 1900s, and this provided the entrée for Detroit. The first great producer of a gasoline powered car was Olds Motor Works, which was a leading engine producer located in Lansing, MI not far from Detroit. Olds began producing automobiles in Lansing and Detroit in 1901. It produced a two seater car powered by a one cylinder gasoline engine that became the first big seller in the industry. At its peak in 1905 it produced 6,500 cars and was the leading firm in the industry, capturing 26% of the market. Only one of the leaders in 1900, White Sewing Machine, was still a leader of the industry in 1905, but not for long. White and Pope were producers mainly of electric automobiles and Locomobile produced steam powered cars, and the shift to the internal combustion engine hurt all three firms.

Five other firms in the Detroit area also attained the ranks of the leaders in 1905, and collectively the Detroit-area producers accounted for 58% of the market. Olds played a key role in the creation of four of these firms. Olds subcontracted all of its parts to local businesses. Its two main subcontractors, Leland and Faulconer and the Dodge Brothers, played a key role in the success of Cadillac and Ford Motor Co., which were the number two and four firms in 1905. Cadillac was actually founded by Henry Ford in Detroit in 1902, but Henry Leland of Leland and Faulconer was quickly brought in to manage the company after the stockholders lost patience with Ford's slow completion of finished cars. Henry Ford went on to found the Ford Motor Company in Detroit in 1903 with help from the Dodge Brothers, who agreed to produce all of Ford's engines, transmissions, and axles in exchange for 10% of Ford's stock. Another one of Olds' subcontractors, Benjamin Briscoe, initially financed Buick, which was the number eight firm in 1905.[12] Reo Motor Car Co., which was tied for fifth place in 1905, was a spinoff of Olds Motor Works. It was founded by Ransom Olds, who headed Olds Motor Works but left after an argument with its top stockholder over how to organize production. Another one of the leaders in 1905 that was not located in Detroit but would later move there, Maxwell Briscoe, was also descended from Olds Motor Works. It was founded by an ex-Olds employee who had co-founded his own firm, Northern Manufacturing Co., before co-founding Maxwell Briscoe with Benjamin Briscoe.[13]

In the next five years, the share of production accounted for by leading firms in the Detroit area increased to 65%, largely driven by spinoffs of the leaders. After the departure of Ransom Olds, a number of other Olds' employees left to found their own firms, and Olds Motor Works declined and dropped out of the ranks of the leaders by 1910. This was counterbalanced by the success of Ford, itself a spinoff of Cadillac, and five spinoffs from Olds, Cadillac, and Ford that made it into the ranks of the leaders: Brush, E.R. Thomas-Detroit, Hupp, Hudson, and Oakland. The other prominent Detroit-area firm was General Motors, which was formed by William Durant, the head of Buick. It combined 27 firms, including Buick, Cadillac, and Olds.[14]

In the next five years spinoffs from the leading firms helped Detroit solidify its position as the capital of the automobile industry, with Detroit-area firms increasing their market share to 83%. Ford introduced the Model T in 1908, and it was a great success, enabling Ford to increase its market share to an astounding 56% by 1915. General Motors was disorganized and its market share declined to 8% and its founder, William Durant, was ousted. Durant went on to found Chevrolet, which developed a car to

[12] Buick was not successful, though, until it was taken over by William Durant, who had developed one of the leading carriage and wagon companies in nearby Flint, MI.

[13] Outside of the Detroit area, the leading firms were mostly experienced producers from other industries. Jeffery had been a leading bicycle producer before selling out its bicycle business and entering automobiles. H.H. Franklin produced die castings, White was a leading sewing machine company, Stoddard produced farm implements, and Packard (nee Ohio Auto. Co.), which would move to Detroit in 1903,, was an electronics producer before entering the automobile industry.

[14] Another one of the leaders, Studebaker, actually produced its cars in Detroit for many years. Studebaker was a leading carriage company based in South Bend, IN. It acceded to the ranks of the leaders by purchasing E-M-F, a Detroit company that evolved out of two other Detroit companies, Northern (an Olds spinoff) and Wayne, under the direction of Walter Flanders, who had been instrumental in reorganizing Ford's production in 1907-1908. The other two new leaders in 1910 outside of Detroit, Willys and Anderson/Union, grew out of established firms that were not producers of automobiles.

compete with the Model T. It captured 1% of the market as of 1915. Two other spinoffs of leading Detroit firms captured significant market shares. The Dodge Brothers severed their relationship with Ford after Ford declined to buy them out and founded their own firm, which by 1915 captured 5% of the market. Saxon was formed by the assistant general manager of E.R. Thomas-Detroit (renamed Chalmers-Detroit) to produce small cars, and it captured 2% of the market by 1915. Out of the 15 leading firms listed in 1915, 13 were located in the Detroit area, and 10 of these firms were spinoffs.

After 1915 the collective market share of the Detroit area firms fluctuated, dropping to 52% in 1920 and then rising to 85% in 1925. General Motors acquired Chevrolet, which it used to eventually displace Ford as the leading producer. Chrysler was formed from Maxwell Motors and Chalmers-Detroit, which had evolved respectively from the spinoffs Maxwell-Briscoe and E.R. Thomas-Detroit, and later acquired the Dodge Brothers to become the number three producer in the industry. Three spinoffs, Durant Motors, Chandler, and Paige-Detroit, ascended to the ranks of the leaders, but none captured a substantial market share.[15] The big three of General Motors, Ford, and Chrysler, all of which were based in Detroit, continued to dominate the industry into the 1960s.

In total, 112 firms entered the automobile industry in the Detroit area from 1895 to 1924, and 54 or 48% were spinoffs. Most of the leaders in the Detroit area were spinoffs, and by 1925 Detroit-area firms totally dominated the industry with 85% of the market.[16] The population of Detroit grew at an unparalleled rate for a large city, increasing from 305,000 in 1900 to 1,837,000 in 1930. Outside of Detroit, spinoffs were much less prominent. They accounted for only 15% of the entrants, and most of the leading firms, including the three most significant, Jeffery/Nash, Willys, and Studebaker, were not spinoffs. Indeed, what distinguished Detroit were its spinoffs. Using longevity

[15] The other short-lived new firm, Dort, which was located in the Detroit area, was founded by J. Dallas Dort, who had been William Durant's partner in the carriage business and had been involved with Durant early on in Buick.

[16] The share of production that actually occurred in the Detroit area was less than the share of output accounted for by the leading Detroit firms. For example, Census figures indicate that the share of U.S. automobile production in the state of Michigan, which was concentrated around Detroit, peaked at 65% in 1914. Much of the dispersal of output was driven by the leading firms establishing branch assembly plants throughout the United States to save on transportation costs (Rubinstein [2002]).

as a measure of performance, spinoffs in the Detroit area survived markedly longer than other Detroit area entrants and markedly longer than both spinoffs and other types of entrants elsewhere. Moreover, the longevity of non-spinoff entrants was comparable in the Detroit area and elsewhere, suggesting that the superior performance of spinoffs in the Detroit area was due to their distinctive abilities and not any benefits from locating in the Detroit area (Klepper [2006b]).

V. Spinoff Analysis

Analogous to the semiconductor industry, the fertility and location, performance, and impetus for the leading spinoffs in the automobile industry are analyzed.

A. Fertility and Location

Nearly all entry into automobiles occurred by 1924, and no spinoffs entered before 1899. Accordingly, the spinoff analysis is confined to the period 1899 to 1924, during which 142 spinoffs entered the industry. This exceeds the 91 spinoffs that were identified in semiconductors, but the list of semiconductor spinoffs is not complete. It excluded spinoffs of lesser firms (which did not make it onto the ICE listings) and the lesser spinoffs of firms on the ICE listings located outside of Silicon Valley.

A total of 96 firms spawned spinoffs. Not surprisingly, the majority—68—spawned only one spinoff. Parents are too numerous to list them all, but the 28 that spawned two or more spinoffs are listed in Table 7. They are divided according to whether or not they produced automobiles in the Detroit area and are ordered by their number of spinoffs and year of entry. For each firm, the total number of its spinoffs and the number that were ever a leading producer (through 1925) are listed along with whether the firm itself was ever a leading producer.

Seven firms had three or more spinoffs, led by Olds Motor Works and Buick/GM with seven spinoffs each. All seven of these firms were located in the Detroit area. Furthermore, all were related to Olds Motor Works. As noted earlier, Buick was initially financed by an Olds subcontractor and Olds' two main subcontractors were instrumental in the success of Cadillac and Ford. Northern was a spinoff of Olds that was co-founded by Jonathan Maxwell, who also co-founded Maxwell-Briscoe, making Maxwell-Briscoe a second generation spinoff of Olds. Last, Hupp was founded by Robert Hupp of Ford, who had initially worked for Olds before moving to Ford. A number of other well known individuals in the industry also worked for Olds during its brief life as an independent producer before being acquired by General Motors. All told, Olds Motor Works had a great impact on the industry, leading one observer of the industry to describe Ransom Olds as the "schoolmaster of motordom." (Doolittle [1916, p. 44])

Table 7 reflects the dominant influence the leading automobile firms had on the spinoff process. Fifteen of the 28 firms that spawned two or more spinoffs and 6 of the 7 that spawned three or more spinoffs were leading firms. Standardizing by the number of years of production, the annual rate of spinoffs was 56/595 = .094 for firms that were ever a leading producer versus 86/3439 = .025 for the other firms. The leading firms were well over five times larger than the other firms, though, so relative to their size their spinoff rate was actually lower than other firms.

A regional breakdown of the fertility of firms indicates that Detroit-area firms were considerably more fertile than firms elsewhere. The annual spinoff rate for firms in the Detroit area was 59/642 = .091 versus 83/3392 = .024 for other firms. This difference persists even controlling for differences in the quality of firms in Detroit and elsewhere. Among firms that were ever a leading producer, the annual spinoff rate was 37/234 = .158 for firms in the Detroit area versus 19/361 = .053 for firms elsewhere, and among the other firms the annual spinoff rate was 22/408 = .054 for Detroit-area firms and 64/3031 = .021 for firms elsewhere.

Spinoffs generally located close to their parents--110 of the 145 spinoffs located within 100 miles of their parents. This was especially true for spinoffs of Detroit-area firms—50 of these 61 spinoffs located in the Detroit area as well.

Table 8 reports the annual rate at which firms spawned spinoffs at different ages. In contrast to semiconductors, a number of spinoffs occurred after their parents were dated as exiting the automobile industry—36 in total, with 13 occurring one year after their parent exited, 8 two years, 4 three years, two four years, and 9 others between 5 and 11 years after their parent exited.[17] To facilitate a comparison with semiconductors, only

[17] In part, this is due to the more comprehensive listing of automobile spinoffs. Many of the automobile firms that spawned spinoffs after they exited were short-lived producers, whereas the ICE listings did not include comparable semiconductor producers and thus their spinoffs were never identified. Second, a

the 106 spinoffs that occurred during the years their parents produced automobiles are considered. Table 8 indicates that if all firms are included, the annual spinoff rate rises sharply from ages 1-5 to 6-10 and then drops by about a third (but not significantly) and stays roughly constant from ages 11 to 30 (combining the last two age brackets to compensate for the small number of years of production at ages 26-30 yields an annual spinoff rate of .030, comparable to the spinoff rate in the age brackets 11-15 and 16-20). The inclusion of all firms in the analysis depresses the spinoff rate at younger ages, however, because there are many short-lived firms in the sample and these firms had few spinoffs. Table 8 indicates that if the analysis is restricted to the 96 firms with spinoffs, as would be the case if fixed effects were used to control for firm differences, the annual spinoff rate rises from ages 1-5 to 6-10 (but not significantly) and then falls with age (if the last two age brackets of 21-25 and 26-30 are combined, the annual spinoff rate reaches a trough of .058 for ages 21-30).[18]

Smith identified all the firms that were acquired and who acquired them. Among the 713 firms, 46 were acquired (by 1925) by another automobile firm (and thus exited as independent automobile producers) and another 120 were acquired by a non-automobile firm (these firms were classified as continuing producers). This provides a large sample to assess the effects of acquisitions on the spinoff rate. For both types of acquisitions, the rate at which spinoffs occurred at the acquired firm up to one year before and two years after their acquisition was analyzed. This allows for acquisitions to have an effect before they are officially consummated and to take up to two years to affect the spinoff rate.

Consider first the 46 firms that were acquired by another automobile firm. Collectively they experienced 14 spinoffs in the four-year interval considered, for an annual spinoff rate during this period of 14/180 = .078.[19] The annual spinoff rate for these firms in all prior years and for firms that were not acquired by other automobile

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number of the spinoffs that occurred after exit were in firms that exited by being acquired by another automobile firm. Few instances of such acquisitions occurred among the semiconductor firms on the ICE listings. Last, in a few instances of spinoffs being founded many years after the exit of their parent firm, the identification of the parent firm may be incorrect The founder of the spinoff might have worked at subsequent automobile firms without this necessarily showing up in the *Standard Catalog*.

[18] The fall from 6-10 to 11-15 is significant, but none of the subsequent falls are significant.

firms was 107/3854 = .028, suggesting that acquisitions increase the probability of spinoffs. The higher spinoff rate around the time of acquisitions could, however, be due to characteristics about acquired firms that make them more likely to have spinoffs at all times.[20] To control for this possibility, the timing of spinoffs for the 16 acquired firms that had one or more spinoffs is analyzed. They had 14 spinoffs in the four-year interval around when they were acquired, for an annual spinoff rate of 14/64 = .219, versus an annual spinoff rate of 13/100 = .130 in their prior years of production (difference not significant). This suggests that acquisitions do raise the spinoff rate.[21]

Being acquired by a non-automobile firm also seems to increase the spinoff rate. The 120 firms that were acquired by non-automobile firms experienced an annual spinoff rate in the four-year interval around their acquisition of 20/530 = .038.[22] In contrast, the annual spinoff rate of these firms in other years and of other firms that were not acquired by non-automobile firms is 89/3615 = .025 (difference not significant). Again, this differential could be due to characteristics of acquired firms that make them more likely to have spinoffs at all times.[23] Focusing on the 29 firms with spinoffs that were acquired by a non-automobile firm, their annual spinoff rate in the 34 four-year intervals around their acquisitions (some were acquired multiple times) was 20/132 = .152 versus an annual spinoff rate of 15/215 = .070 during the rest of their automobile lifetimes. Similar to acquisitions by automobile firms, this suggests that acquisitions by non-automobile firms increase the spinoff rate.

B. Performance of Spinoffs

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[19] Two of the firms did not have a full four-year interval because of when they exited, which is why collectively the 46 firms had only 180 rather than 184 production years in the four-year interval around their acquisition.

[20] Consistent with this, among the 46 acquired firms 8 or .174 had one or more spinoffs whereas among the other 667 firms 88 or .132 had one or more spinoffs (difference not significant).

[21] Alternatively, it could be that the spinoff rate was greater for all firms around the end of their automobile lifetimes. To check this, the timing of spinoffs in the 68 firms with spinoffs that exited by 1924, but not by being acquired by another automobile firm, was analyzed. These firms had an annual spinoff rate of 30/272 = .110 in the four-year interval around their exit year versus an annual spinoff rate of 37/380 = .097 in their prior years of production. This difference, which is not significant, is too small to explain the higher fertility of firms after being acquired.

[22] Some of these firms were acquired multiple times by non-automobile firms, which is why the denominator is greater than 480 years.

[23] Consistent with this, among the 120 acquired firms, 29 or .242 had one or more spinoffs whereas among the other 593 firms only 67 or .115 had one or more spinoffs.

To evaluate the relationship between the performance of spinoffs and their parents, firms are divided again according to whether they were ever a leading producer. Those that were had 56 spinoffs, 11 of which also became a leading producer, for a rate of 11/56 = .196. The other firms spawned 86 spinoffs, and 4 of these became a leading producer, for a rate of 4/86 = .047. Thus, the spinoffs of leading firms were themselves much more likely than the spinoffs of lesser firms to attain the ranks of the leaders. Standardizing by years of production, the annual rate at which firms spawned spinoffs that became leading producers was 11/595 = .018 for firms that were themselves leading producers and 4/3439 = .0012 for other firms. Clearly, the likelihood of spawning a leading spinoff was much greater for the leading producers.

C. Origins of the Leading Spinoffs of Detroit-area Firms

Klepper [2006a] tracks the origins of the leading spinoffs of firms located in the Detroit area. The reasons for their formation and their sources of finance are summarized in Table 9. Two reasons stand out for the spinoffs: managerial conflicts and strategic disagreements.

Managerial conflicts were already noted regarding the formation of Ford, Reo, and the Dodge Brothers. Henry Ford was pushed out of Cadillac when he took longer than his stockholders desired to produce finished cars. Ransom Olds was pushed out of Olds Motor Works, the company he headed, over a dispute with his major stockholder about whether the production process should be modified to lower the defect rate of his automobiles. Ford Motor Company had been integrating backward for many years and the Dodge Brothers feared they would become obsolete. They severed their relationship with Ford when Ford dawdled over buying them out. Both of William Durant's spinoffs, Chevrolet and Durant Motors, were also the result of disputes over his management style at General Motors. Soon after he formed GM, he was ousted by its bankers because he did not attend satisfactorily to integrating the numerous firms he had acquired. He later used Chevrolet to reacquire GM, but once again was ousted after a buying spree left the company disorganized.

Many other spinoffs were formed as the result of strategic disagreements over the types of cars to produce, particularly regarding the prospects of smaller, less expensive cars that ultimately dominated the market. Olds, Cadillac, E.R. Thomas-Detroit, and

General Motors all drifted over time toward the production of larger automobiles. E.R. Thomas-Detroit was founded by the chief engineer and head of sales at Olds after support for a new, smaller car they championed was withdrawn at the last minute. Subsequently, they teamed with two other Olds' employees to found Hudson after the new head of E.R. Thomas-Detroit declined to produce a new, smaller car they had developed to compete with the Model T. Maxwell-Briscoe was co-founded by Jonathan Maxwell after the car he designed for Northern, an Olds' spinoff that he co-founded, was abandoned in favor of a larger car. Brush and Oakland were both founded by Alanson Brush, Cadillac's leading engineer, over a dispute concerning his patents. Both companies developed new cars that were much smaller than the luxury cars Cadillac gravitated toward over time. Saxon was founded to produce a small car that its parent, Chalmers-Detroit (the later name of E.R. Thomas-Detroit) did not want to pursue (although Hugh Chalmers, its head, did help finance Saxon). Last, Chandler was founded to produce a smaller and less expensive version of the luxury car that its parent, Lozier, was unwilling to develop.

Not surprisingly, the cars produced by spinoffs initially shared features with those of their parents, but invariably they were sufficiently different to appeal to different buyers than their parents' cars. This was not only true of spinoffs formed to produce smaller, less expensive cars than favored by their parents, but also those that resulted from management conflicts. For example, Ford concentrated on inexpensive cars for the masses while its parent, Cadillac, evolved into a producer of large luxury cars. Similarly, Reo introduced a moderately priced car while its parent, Olds Motor Works, also evolved into producing ever larger and more expensive cars. Brush and Oakland both produced much smaller cars than its parent, Cadillac. Chevrolet continued the development of smaller, less expensive cars that William Durant had initiated at Buick but had been abandoned at General Motors after his ouster. The Dodge Brothers developed a sturdier and improved version of the Model T that appealed to buyers that wanted a better car than the Model T and were willing to pay for it.

The leading spinoffs were financed in various ways. Some were financed by experienced automobile men, such as E.R. Thomas-Detroit, which was financed by E.R. Thomas, who headed his own automobile firm. The Briscoe Brothers, who were one of Olds' original subcontractors, also financed some of the leading spinoffs. Other spinoffs, including Reo and Durant, were financed by individuals who had purchased stock in the prior ventures of their founders. In other cases relatives provided finance or the founders were sufficiently wealthy from their past automobile success to finance their own ventures. Each financier had his own distinctive knowledge about the industry or the founders of the spinoffs to evaluate the prospects of these new ventures. As noted, the leading spinoffs invariably developed cars that appealed to different buyers than the cars of their parents, and in the process expanded the market for automobiles. No doubt this played an important role in the tremendous growth of the industry, which averaged over 20% a year from 1899 to 1924 when nearly all the spinoffs in the industry entered.

VI. Discussion

Many parallels exist between how the automobile and semiconductor industries ended up agglomerated in Detroit and Silicon Valley.

Initially both industries were centered in areas where producers in related industries were concentrated. A fundamental shift in technology, to internal combustion engines in autos and silicon in semiconductors, opened up opportunities for new entrants, and pioneers entered in Detroit and Silicon Valley. These pioneers unleashed a reproductive process in which better firms spawned more and better spinoffs, especially at middle age. With spinoffs not moving far from their geographic origins, the result was a proliferation of top firms around the original pioneers. Once this process got going, it appears to have been self-reinforcing, with firms of all qualities being more likely to spawn spinoffs in Detroit and Silicon Valley than elsewhere. The leading spinoffs were largely the result of managerial and strategic disagreements within the top firms, which were sometimes reluctant to pursue new ideas or unproductively imported practices used in other industries and firms. Spinoffs were financed by individuals and firms with their own distinctive knowledge. They expanded the range of activities in Detroit and Silicon Valley, both of which became extraordinary engines of economic growth.

Conventional agglomeration economies related to knowledge spillovers, labor pooling, and specialized input suppliers (cf. Rosenthal and Strange [2004]) were not needed to tell this story. While surely beneficial, these economies may be more the result than the cause of agglomerations. Indeed, the fact that the superior performance of

Detroit firms was confined to spinoffs suggests that agglomeration economies benefiting all firms were not operative in Detroit. One can only wonder whether they were important in the emergence of Silicon Valley as the center of semiconductor production.

All the distinctive characteristics of Silicon Valley, including Stanford, venture capital, and vertically specialized firms with flat hierarchal structures, were also not needed to tell this story. Indeed, none of these characteristics applied to Detroit and the automobile industry, yet its development closely paralleled that of Silicon Valley. And clearly, Silicon Valley did not represent the emergence of a new type of entrepreneurial economy driven by spinoffs. In addition to Detroit, spinoffs played a key role in the evolution of Akron as the center of the U.S. tire industry at the turn of the twentieth century (Buenstorf and Klepper [2005, 2006]), and the old footwear industry as well appears to have proceeded through a similar evolution (Sorenson and Audia [2000]). It appears that this form of regional economic development is at least 50 years older than Silicon Valley.

Klepper and Thompson [2006] offer a formal theoretical model of disagreements to explain all the salient patterns regarding spinoffs in autos and semiconductors, which are shared by a number of other technologically progressive industries. In their model, spinoffs result when meritorious ideas of talented employees are rejected because of the inability of top management to recognize the value of the ideas and/or the talents of the employees. The performance of firms is based on the quality of their employees, so the best firms are the leading candidates to spawn spinoffs. The chances of such firms spawning spinoffs are greater the less able incumbent management is to judge new ideas that arise within the firm.

Fairchild and Olds exemplify these themes. Both were pioneers with many talented employees. Both were hampered by management with limited knowledge about their industries. Fairchild Semiconductor was controlled by its parent, Fairchild Camera and Instrument, which had limited insight about how to manage a semiconductor firm. This contributed to tensions over stock options, recognition of employee achievements, and poor management choices that in turn played an important role in many of the spinoffs from Fairchild. Olds Motor Works was ultimately controlled and managed by its chief stockholder and his son, who both had little experience in manufacturing. This too contributed to managerial tensions and poor strategic choices, which in turn also played an important role in spinoffs from Olds. Fairchild remained as a leading firm much longer than Olds and thus had many more spinoffs in total than Olds, but Olds' influence lived on through the other successful firms it indirectly influenced and through its spinoffs. The result was an extraordinary number of spinoffs in Silicon Valley and Detroit.

In Klepper and Thompson's model, spinoffs pursue ideas that originate within their parent firms but that their parents decline to develop. Because their ownership is unclear, such ideas are inherently difficult to protect from imitation Consequently, spinoffs invariably involve spillovers that benefit other firms. The development of ICs is illustrative. Amelco and Signetics were formed to push forward the technology of ICs after Fairchild did not aggressively pursue this new market. Once Fairchild saw how successful they were, it countered with its own innovative efforts and captured 30% of this lucrative market (Lécuyer [2006, pp. 238-250]). Sometimes the beneficiaries of spinoffs are other firms and not their parents. For example, Intel's initial innovative efforts resulted in the development of MOS computer memories, which opened up a new market that many firms subsequently entered. Parallels abound in automobiles. Chevrolet, a spinoff from General Motors, is illustrative. General Motors acquired Chevrolet five years after it was formed. Subsequently, it improved Chevrolet's operations sufficiently that it was able to use Chevrolet to displace Ford as the leading automobile producer. Eventually this even led Ford to scrap the Model T, which had grown obsolete, and develop a new, innovative car (Hounshell [1984, pp. 263-292]).

To the extent spinoffs involve spillovers that benefit other firms, the rate at which spinoffs are created will not be socially optimal, and anything that stimulates the formation of spinoffs will be socially beneficial. Judging from the exceptional spinoff fertility of firms in Detroit and Silicon Valley, agglomerations appear to stimulate the formation of spinoffs. As such, agglomerations are as much social as regional engines of economic growth and deserve to be promoted.

More fundamentally, if spinoffs create social benefits, then it is desirable to use public policy to promote their formation. At a minimum, policies should be undertaken to prevent incumbent firms from suppressing spinoffs in antisocial ways. Incumbents naturally want to discourage spinoffs to prevent the loss of valuable employees, which was especially prevalent in the semiconductor industry. Having lived through such losses at Fairchild, the founders of Intel were determined to prevent it from recurring there. They committed to a strategy of using the threat of trade secret litigation to discourage spinoffs regardless of whether trade secrets were involved (Jackson [1998]). This clearly seems detrimental to the public interest. Perhaps constraints should be placed on the use of trade secret litigation to discourage spinoffs or special punishments should be created for firms that use trade secret litigation in this fashion.

Public policy could also be used more proactively to encourage spinoffs. One way employers can legally restrict spinoffs is by requiring employees to sign non-compete covenants. Some states, however, do not allow non-compete covenants to be enforced. California is one such state and so was Michigan after 1905, during the formative era of the automobile industry. Recent studies suggest that non-compete covenants do affect the startup rate (Stuart and Sorenson [2003]) and more generally employee mobility (Marx et al. [2006]). Thus, states might want to consider restricting the use of non-compete covenants, perhaps limiting the extent to which they can be used against new firms.

Regions commonly try to galvanize economic activity by attracting firms to locate there. Whether such efforts are socially beneficial is unclear, but the findings concerning spinoffs are suggestive about the kinds of firms worth attracting. It would be best to lure firms that are more likely to spawn spinoffs. Young industries would be a natural target as they are typically characterized by greater entry and thus more spinoffs. It would be ideal to attract successful firms in such industries given their greater spinoff rate, but no doubt these are the most difficult firms to induce to move. An alternative strategy would be to encourage such firms to set up branches in a region.

Another strategy regions use to stimulate activity is to establish venture capital funds to support firms in certain strategic industries, particularly ones where spinoffs are more likely. This makes sense if capital is the key to new firm formation. At the start of the semiconductor industry, though, Silicon Valley was certainly not blessed with abundant sources of capital. Detroit was a substantial sized city, but lots of other cities had comparable sources of capital. Neither city ultimately had much trouble attracting investors. Rather, the key to both regions was the creation of firms that investors wanted to support. In the absence of such firms, greater availability of venture capital is unlikely to be productive and could even be wasteful.

The overriding lesson of Detroit and Silicon Valley is that progress in their respective industries required new firms, and the likely origin of these new firms were successful firms in the industry itself. This will hardly be true in all industries, but when it is true regions need to have in place legal and economic policies to enable talented employees to leave established firms and venture out on their own. By creating the right conditions, regions blessed with pioneers in a new industry can unleash a torrent of activity that could create the next Detroit or Silicon Valley.

Table 1: Market Shares of Leading North American Merchant Producers, 1957-1990

Receiving Tube Firms	Entry Year[a]	Metropolitan Location	57	60	63	66	75	80	85	90
General Electric	1951	Syracuse, NY	9	8	8	8	C	C	C	C
RCA	1951	Camden, NJ	6	7	5	7	4	3	2	
Raytheon	1951	Boston, MA	5	4	--	--	1	1	1	0.5
Sylvania	1953	New York, NY	4	3	--	--				
Westinghouse	1953	Philadelphia, PA	2	6	4	5	C	C	C	C
Philco-Ford	1954	Elmira, NY	3	6	4	3				
Other Early Leaders										
Texas Instruments	1953	Dallas, TX	20	20	18	17	20	19	18	15
Transitron	1953	Boston, MA	12	9	3	3	0.5			
TRW	1954	Los Angeles, CA	--	--	4	--	C	C	C	C
Hughes	1955	Los Angeles, CA	11	5	--	--	C	C	C	C
General Instrument	1955	Long Island, NY	--	--	--	4	3	2	1	0.5
Delco Radio (GM)	1956	Kokomo, IN	--	--	--	4	C	C	C	C
Fairchild	1957	Mountain View, CA	--	5	9	13	9	7	5	A
Motorola	1958[b]	Phoenix, AZ	-	5	10	12	8	11	13	17
Later Leaders										
Signetics	1961	Sunnyvale, CA			--	--	5	6	5	
Analog Devices	1965	Boston, MA				--	1	1	2	2
AMI	1966	Santa Clara, CA				--	4	2	1	1
National	1967	Santa Clara, CA					10	11	10	9
Harris	1967	Melbourne, FL					2	3	3	4
Intel	1968	Santa Clara, CA					7	10	10	17
AMD	1969	Sunnyvale, CA					2	5	7	6
Mostek	1969	Dallas, TX					2	6	A	
Micron Technology	1978	Boise, ID						--	0.5	2
VLSI Technology	1979	San Jose, CA						--	1	2
LSI Logic	1980	Milpitas, CA						--	2	3
Silicon Valley Share										
Leading firms[c]			0	5	9	13	38	42	42	38
Leaders + other ICE firms[c]							43	48	49	47

-- Firm was producer, but no market share data reported
C—captive producer in the listing of Integrated Circuit Engineering (ICE)
A—acquired by a semiconductor producer

a Dates for receiving tube firms and early leaders based on Tilton [1971]
b According to Tilton [1971], Motorola used semiconductors only for its own purposes before 1958
c Includes Raytheon, which was based in Silicon Valley as of 1975.

Sources: See Tilton [1971] for sources for 1957, 1960, 1963, and 1966 market share data; the 1975, 1980, 1985, and 1990 market shares are based on annual compilations of ICE

Table 2: Spinoffs of Merchant Semiconductor Producers

Silicon Valley Producers

Firm	Years (through 1986)	# Spinoffs	#ICE Spinoffs	# Top 20 Spinoffs	Top 20 Firm
Fairchild	1957-1986	24	14	7	Y
National	1967-1986	9	4	1	Y
Intel	1968-1986	6	6	2	Y
Signetics	1961-	5	2	1	Y
Intersil	1967	4	2	0	Y
Synertek	1973	4	3	1	Y
Semi Processes	1975	4	1	0	
AMI	1966	3	2	0	Y
AMCC	1979	3	2	1	
Seeq	1981	3	3	1	
Amelco	1961	2	0	0	Y
Micro Power	1971	2	1	0	
Raytheon/Rheem	1961	1	0	0	Y
Siliconix	1963	1	0	0	Y
Avantek	1965	1	0	0	
AMD	1969	1	1	1	Y
Exar	1971	1	1	0	
Cal-tex	1971	1	0	0	
Nitron	1972	1	0	0	
Zilog	1974	1	1	1	Y
Supertex	1976	1	0	0	
Exel	1983	1	0	0	

Non-Silicon Valley Producers

Firm	Years (through 1986)	# Spinoffs	#ICE Spinoffs	# Top 20 Spinoffs	Top 20 Firm
General Instrument	1960-1986	4	2	0	Y
Texas Instruments	1952-1986	3	3	2	Y
Motorola	1958-1986	2	2	1	Y
Mostek	1969	2	2	2	Y
RCA	1950-1986	1	1	0	Y

Table 3: Fertility Rates by Age Bracket

Ages	All Firms	All Parents
1-5	.040 (18/448)	.134 (18/134)
6-10	.062 (18/292)	.151 (18/119)
11-15	.132 (27/205)	.260 (27/104)
16-20	.162 (20/123)	.263 (20/76)
21-25	.074 (5/69)	.106 (4/47)
26-30	.077 (3/39)	.120 (3/25)
31-35	.000 (0/27)	.000 (0/10)
36-40	.000 (0/9)	.000 (0/2)

Table 4: Performance of Spinoffs and Their Parents

Firm	% Spinoffs on ICE list (SV spinoffs only)	% Spinoffs in Top 20 firms
Top 20	.574 (35/61)	.260 (19/73)
Top 20 minus Fairchild	.568 (21/37)	.245 (12/49)
Other firms	.444 (8/18)	.111 (2/18)

Table 5: Origins of Leading Spinoffs of Silicon Valley Producers

Spinoff	Year	Parent	Reasons	Finance
Fairchild	1957	Shockley Laboratories	Strategic disagreement (silicon transistors), management conflict	Fairchild Camera and Instrument
Amelco	1961	Fairchild	Strategic disagreement (ICs)	Teledyne
Signetics	1961	Fairchild	Strategic disagreement (ICs), management conflict	Investment banks
Electronic Arrays	1967	GME	Management conflict after acquisition by nonsemiconductor firm	N.A.
Intersil	1967	Union Carbide	Compensation practices (stock options), management conflict with nonsemiconductor parent	SSIH and Olivetti
National	1967	Fairchild	Compensation practices (stock options), management conflict with nonsemiconductor parent	National Semiconductor
Intel	1968	Fairchild	Management conflict, technical frustration (MOS)	Venture capital
AMD	1969	Fairchild	Management conflict after CEO hired from outside firm	Minimal capital ($100,000)
Zilog	1974	Intel	Personal tensions	Exxon
VLSI	1979	Synertek	Management conflict after acquisition by nonsemiconductor firm	Venture capital
LSI Logic	1980	Fairchild	Management conflict after acquisition by nonsemiconductor firm	Venture capital
Linear	1981	National	Strategic disagreement (linear circuits)	Venture capital
Cypress	1982	AMD	Strategic disagreement (CMOS)	Venture capital

N.A.—not available

Table 6: Market Shares of Leading U.S. Automobile Firms, 1900-1925

Early Entrants	Entry Yr.	Entry Location	1900	1905	1910	1915	1920	1925
Pope	1895	Hartford, CT	36					
Stanley	1896	Watertown, MA		2				
Locomobile	1899	Bridgeport, CT	18					
Knox	1900	Springfield, MA	0.3					
Packard	1900	Warren, OH/Detroit, MI		2	2			1
H.H. Franklin	1900	Syracuse, NY		4				
White Sewing M.	1901	Cleveland, OH	0.02	4				
Olds/GM	1901	Detroit/Lansing, MI		26		1	2	1
Cadillac/GM	1902	Detroit, MI		16	6	2	1	1
Jeffery/Nash	1902	Kenosha, WI		16			2	3
Later Entrants								
Studebaker	1902	South Bend, IN			8	5	3	4
Anderson/Union	1902	Anderson, IN			2			
Ford	1903	Detroit, MI		7	18	56	22	44
Maxwell Briscoe/ Maxwell/Chrysler	1903	Tarrytown, NY/Detroit, MI		3	6	5	2	4
Buick/GM	1903	Flint, MI		3	17	5	6	5
Willys	1903	Terre Haute, IN			9	10	6	6
Reo	1904	Lansing, MI		4	4	2		
Stoddard	1904	Dayton, OH		1				
E.R. Thomas-Det./Chrysler	1906	Detroit, MI			4	1		
Brush	1907	Detroit, MI			6			
Oakland/GM	1907	Pontiac, MI			2	1	2	1
Hupp	1909	Detroit, MI			3	1	1	3
Hudson	1909	Detroit, MI			3	1	2	7
Paige-Detroit	1909	Detroit, MI						1
Chevrolet/GM	1911	Flint, MI				1	6	12
Saxon	1913	Detroit, MI				2		
Chandler	1913	Cleveland, OH					2	
Dodge Brothers/Chrysler	1914	Detroit, MI				5	7	5
Dort	1915	Flint, MI					1	
Durant	1921	New York, NY					3	
Detroit-area Firms			0	58	65	83	52	85

Table 7: Spinoffs of Automobile Producers

Detroit-area Producers*

Firm	Years (through 1924)	# Spinoffs	# Leading Spinoffs	Leading Firm
Olds	1901-1908	7	3	Y
Buick/GM	1903-1924	7	2	Y
Cadillac	1902-1908	4	3	Y
Ford	1903-1924	4	2	Y
Maxwell Briscoe/Maxwell	1904-1924	4		Y
Northern	1902-1910	3	1	
Hupp	1909-1924	3		Y
Packard	1900-1924	2		Y
Jackson	1902-1918	2		
C.H. Blomstrom	1903-1909	2		
Imperial	1909-1917	2		
Chevrolet	1911-1916	2		Y
Saxon	1913-1922	2		Y

Non-Detroit Area Producers*

Firm	Years (through 1924)	# Spinoffs	# Leading Spinoffs	Leading Firm
Haynes Apperson	1895-1924	2		
Duryea	1896-1907	2		Y
F.B. Stearns	1898-1924	2		Y
Berg	1902-1906	2		
Jeffery	1902-1924	2		Y
Willys	1903-1924	2		Y
Metz/American Chocolate	1903-1923	2		Y
Stoddard	1903-1910	2		Y
Lozier	1904-1915	2	1	
York	1905-1917	2		
Palmer & Springer	1907-1914	2		
Single Center	1907-1909	2		
Ideal	1911-1924	2		

* Classified in Detroit area if majority of years of production there

Table 8: Fertility Rates by Age Bracket

Ages	All Firms	All Parents
1-5	.019 (47/2500)	.121 (47/390)
6-10	.045 (38/847)	.158 (38/241)
11-15	.031 (12/388)	.085 (12/142)
16-20	.030 (6/200)	.068 (6/88)
21-25	.024 (2/84)	.044 (2/45)
26-30	.067 (1/15)	.143 (1/7)

Table 9: Origins of Leading Spinoffs of Detroit-area Producers

Spinoff	Year	Parent	Reasons	Finance
Ford	1903	Cadillac	Managerial/strategic disagreement (time to production)	Businessmen, Dodge Brothers
Reo	1904	Olds Motor Works	Management conflict	Past stockholders
Maxwell-Briscoe	1904	Northern	Strategic disagreement (smaller car)	Auto man
E.R. Thomas-Detroit	1906	Olds Motor Works	Strategic disagreement (smaller car)	Auto manufacturer
Brush	1907	Cadillac	Dispute over patents	Auto man
Oakland	1907	Cadillac	Dispute over patents	Carriage manufacturer
Hudson	1909	Olds Motor Works	Strategic disagreement (smaller car)	Relative
Hupp	1909	Ford	Desire to be entrepreneur	Minimal capital
Paige-Detroit	1909	Reliance Motors	Abandoned autos for trucks	Businessman
Chevrolet	1911	Buick/General Motors	Management conflict	Self financed
Saxon	1913	E.R. Thomas-Detroit (Chalmers-Detroit)	Strategic choice (smaller car)	Auto men
Chandler	1913	Lozier	Strategic conflict (smaller car)	N.A.
Dodge Brothers	1914	Ford	Management conflict	Self financed
Durant Motors	1921	Buick/General Motors	Management conflict	Past stockholders

N.A.—not available

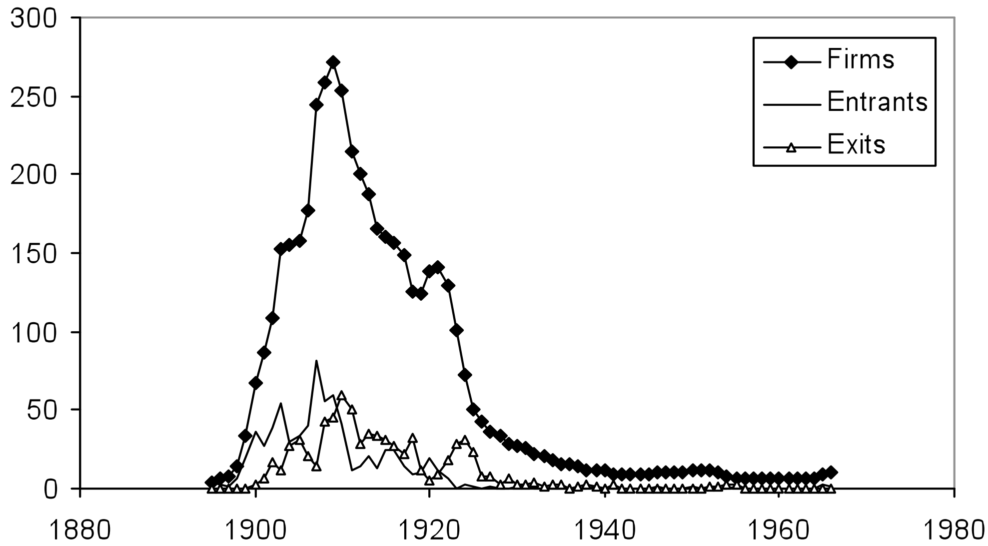

Figure 1: Entry, Exit, and Number of Firms

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